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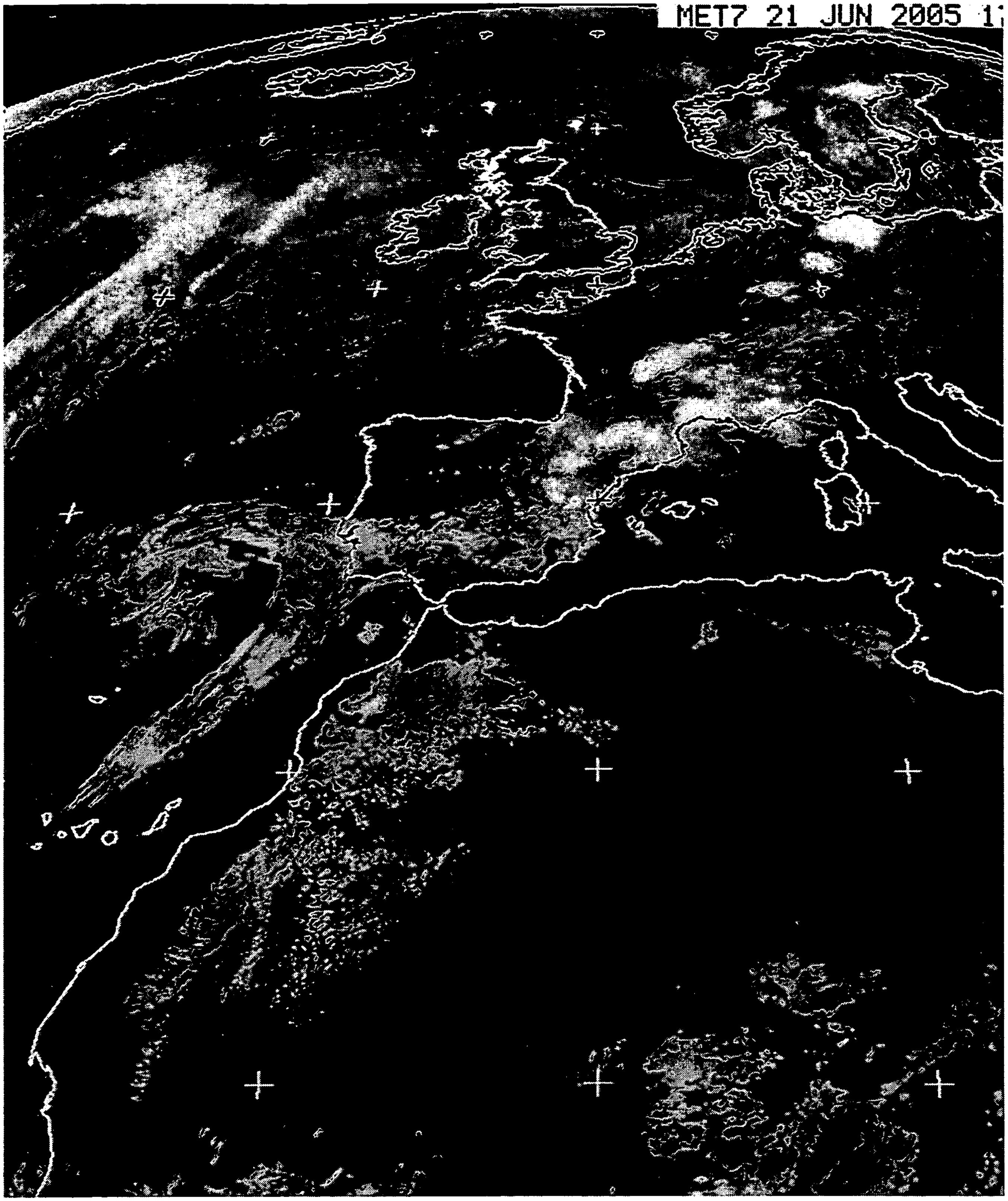

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Determining cloud cover

E. Linacre and B. Geerts 1/'98

The amount of cloud cover at various levels (low, middle and high) can be estimated from satellite data. For instance, **Fig 1** shows the estimated global cloud cover from simultaneous observations on a series of geostationary satellites around the world (Note 8.J). Because the image is infrared, the brightness of the clouds is a measure of their heights.

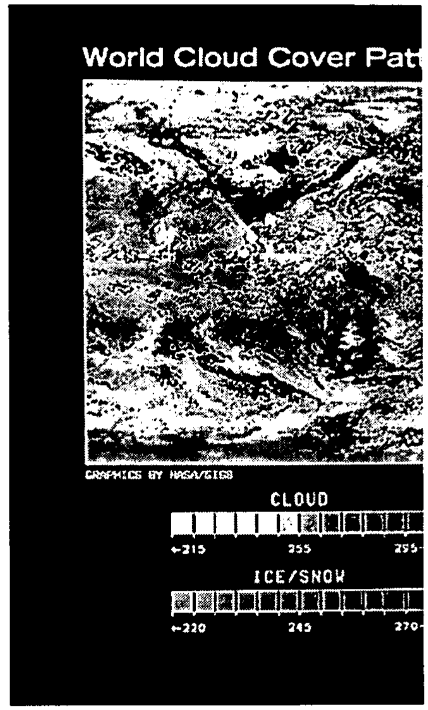

Fig 1. Global cloud cover at 12 (from infrared imagery on 5 geos shadings are a function of the IR NASA/GSFC)

Cloudiness can be calculated by counting the number of cloudy pixels on the satellite image, and this can be done for a large sample, to obtain climatologically meaningful estimates. These satellite-based estimates are generally less than ground-based ones, either by direct human observation or by inference from the duration of bright sunshine (1). The sunshine duration leads to an overestimate of cloudiness when the sun is close to the horizon (before sunset or after sunrise), especially when the cloudiness is cumuliform. Direct human observation attempts to compensate for the apparent obscuration of clear sky near the horizon, by the vertical extent of intervening low and middle clouds, but still most ground-based observers tend to overestimate cloudiness in these circumstances.

Compared to satellite estimates, human observations overestimate cloudiness by about $0.2 - 0.0013\phi$ tenths of cloud (where ϕ is the latitude in degrees), e.g. 0.15 tenths at 40?. This is because cumuliform clouds are more common at lower latitudes. Note that apart from using ?okta? units of cloudiness (i.e. eighths of the sky covered by cloud), we may express the fraction in ?tenths?. In other words, 4 oktas equals 5 tenths.

Complications arise from the fact that thin cirrus would not be seen by the satellite nor influence sunshine-recorder readings, but are apparent to the ground observer. Also, the ground observer sees a much smaller area of sky at any moment, and the size of this area depends on the cloud base height. And near the horizon, the solar intensity is too weak to actuate a sunshine recorder, especially under hazy conditions.

The value of long-term trends of cloudiness suffers from the rather local character of the observations, and from the possible systematic biases between individual surface observers. Therefore value is added to time series of human observations by corroborating them by means of all-sky photographs (2) or satellite imagery, which has been available only for the last few decades.

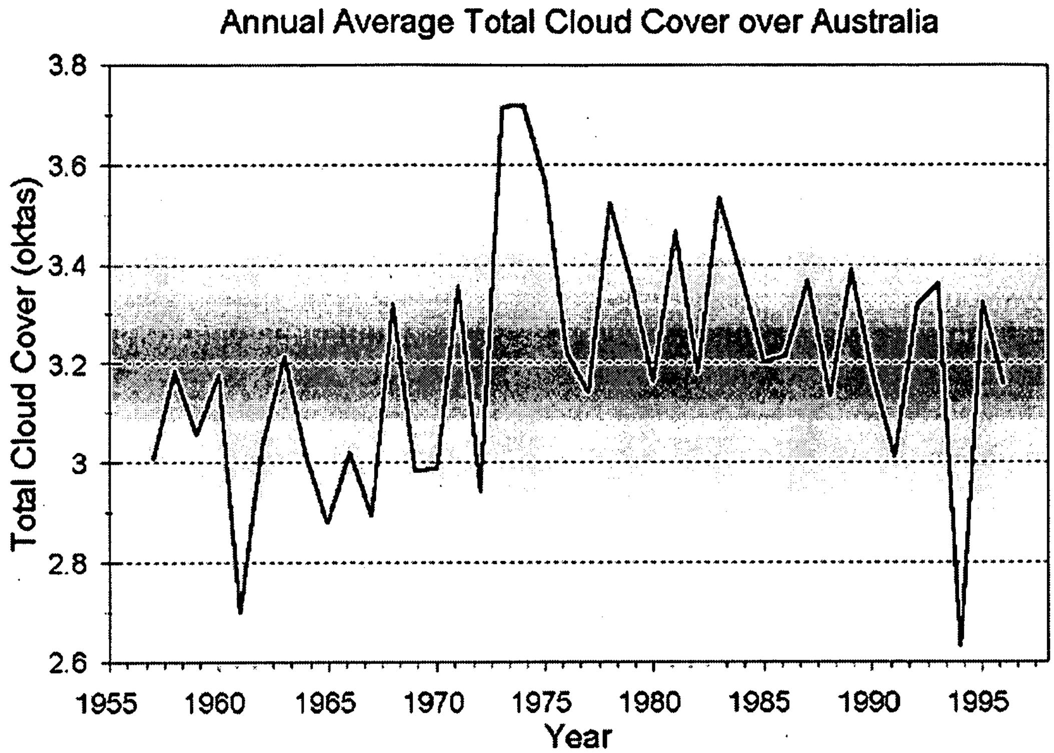

Fig 2: Average total cloud cover in Australia, based on human observations, from 1957 to 1996 (4).

A significant increase of cloudiness between 1910-1989 appears to have occurred in Australia (3). A more recent analysis (4) confirms a slight increase over the past four decades but show that it is largely due to an abrupt change in the early 1970s (**Fig 2**). Most of the rise apparently has occurred in winter and spring. Reported changes in cloud cover elsewhere are generally small and often inconsistent.

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IMAGE COMPARISON FROM TWO CLOUD COVER SENSOR IN INFRARED AND VISIBLE SPECTRAL REGIONS

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The Total Sky Imager (TSI) and The Cloud Infrared Radiometer (CIR-7) are two cloud cover measuring instruments. TSI uses a CCD camera and provide sky images in the visible spectral range, CIR-7 consists of 7 infrared pyrometer sensors working in the window region 9-14 microns. We will present a comparison of images obtained with both instruments and suggest further investigation possibilities.

1. Introduction

Through several reports [1] we have presented the basics and the design of an infrared cloud cover imager called CIR-7. In this material, we will offer a comparison of the CIR-7 imaging capabilities vs. other sky imaging techniques and cloud cover measurement methods.

During an experimental campaign from February until April 2003, CIR-7 was deployed at the Atmospheric Radiation Measurements (ARM) Southern Great Planes (SGP) Central Facility (CF), located in central Oklahoma state, USA. Many other instruments were operational at the same location and time - in particular, the Total Sky Imager (TSI). This work is dedicated to the comparisons of the imaging ability of the two instruments – TSI and CIR-7.

More precisely, we will show the advantages and disadvantages specific to the cloud cover imagery of both instruments.

2. ARM SGP CF Campaign

2.1 Site

The campaign was integrated in the annual program of ARM and took place from February 19 until March 31 2003. Among the participants were Pacific Northwest National Laboratory, Montana State University, Institut d'Aéronomie Spatiale de Belgique, Université du Maine, CERES/NOAA. During this campaign a CIR-7 and a TSI were deployed within less than 50 meters.

2.2 Instruments presentation

The Total Sky Imager (Figure 1) is an automated color imaging system providing day time images and sky cover nebulosity intensity.

Sky images are collected using a CCD color camera pointing up and mounted on a rotating heated hemispherical mirror. A

shadowing band hide the sun spot to prevent CCD camera blooming.

TSI is a day-time imaging system – "grabbing" images begins when the sun elevation is greater than a user defined value. Cloud cover is computed from the red to blue ratio.

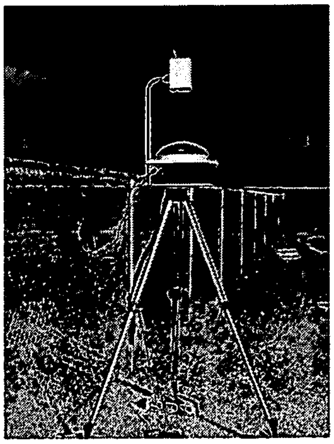

Figure 1 : Total Sky Imager

The CIR-7 (Figure 2) is a ground-based instrument designed and assembled by ATMOS Sarl, France for day and night cloud cover imaging. It operates 7 infrared sensors in spectral range 9-14 mm, each with a 12-degrees Field Of View.

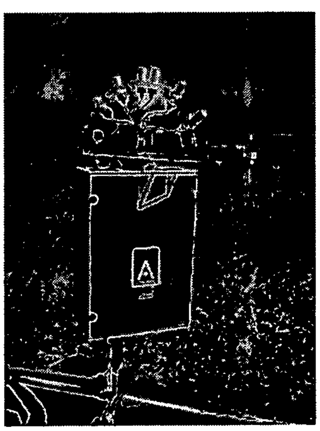

Figure 2 : CIR7

The sensors are mounted at zenithal angles 0, 12, 24, 36, 48, 60 and 72 on a semi-circular azimuthally rotating turret. Figure 2 show the schematic view of the instrument design. They are based on OMEGA OS 65–V-R2-4-BB model pyrometers. The original sensors were modified in order to reduce the total weight from 0.3 to 0.1 kg per sensor, and to prevent the accumulation of liquid water at the optics entrance. The main technical characteristics of the sensors and the instrument are given in Table 1.

Spectral Range	9-14 mm
Temperature range	-57°C +125°C
Temperature accuracy	±1°C
Response time	300 ms
Pyrometer FOV	11.9°
CIR-7 FOV	160°
View zenithal angles	0°, 12°, 24°, 36°, 48°, 60°, 72°
Number of rotation steps for a 360° scan	30
Time for a 360° scan	203s

Table 1. Technical characteristics of the pyrometer

3. Image generation using CIR-7

To obtain a sky image from CIR-7 the turret will have to make 30 rotational steps by 12 degrees each. Sensor integration time is about 300 ms and one rotation takes about 7 seconds.

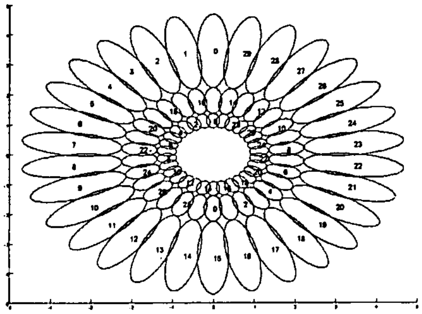

Figure 3 : Step numbering for each measurement cone in parallel plane model. For clarity only sensors with view zenith angles 72, 60 and 48 are shown

This time duration guarantee a good mechanical stabilization of the instrument and that the measurements are performed in the right direction. However, this also leads to obtaining a full scan only every 203s.

Figure 3 shows the step numbering of each direction for three ofthesensors. As we can see we obtain an interlace image like a TV image. Between scan 0 and scan 29 there is a difference of 203 seconds. If clouds are moving quickly then a line often appear in the middle of the scan. If cloud are moving even faster, then some circular shape could be observed in one or more frames.

Image rendering for CIR7 uses parallel plane model – see Figure 4.

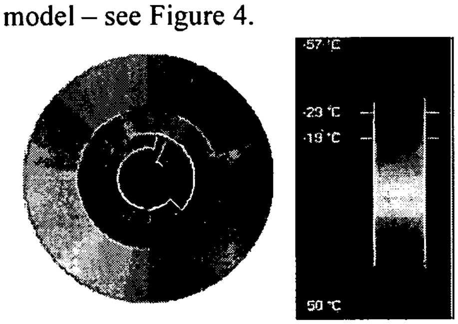

Figure 4 Radar diagram image

For a smoother representation a bilinear interpolation technique is used - Figure 5.

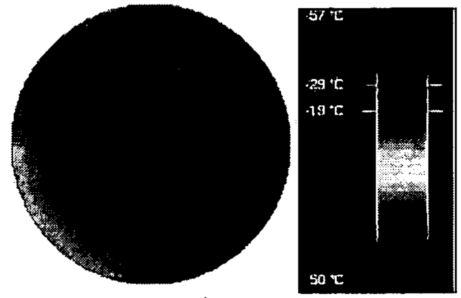

Figure 5 Interpolated radar diagram image

4. Comparison CIR7 and TSI images

As previously shown, sampling time for TSI is 30s and for CIR-7 it is 203s. To compare TSI and CIR-7 images we chose to simulate a CIR-7 image in the visible band. Based on the difference in the sampling times we need to use 8 TSI images in order to simulate one CIR-7 visible image.

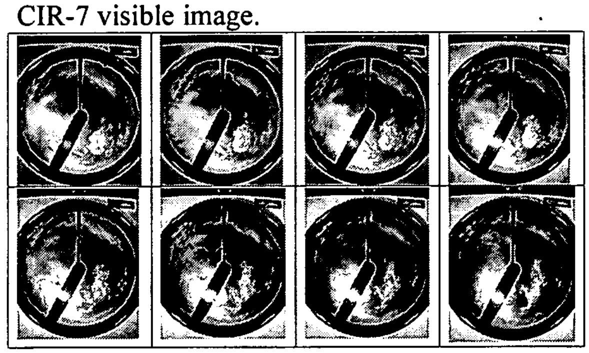

Figure 6 : 8 TSI images used to simulate a CIR-7 image in the visible spectral range.

Intensity of red, green and blue ratio can be evaluated using nearest time sampling of TSI images for a given time of CIR-7 image. In case of time sampling between the TSI times, a linear interpolation is performed (figure 7).

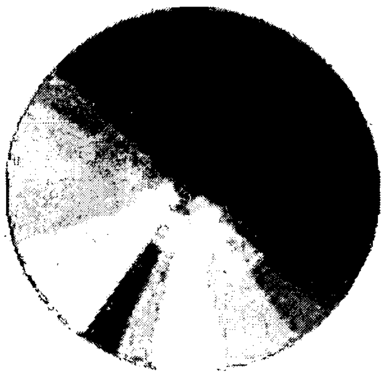

Figure 7 : Simulate CIR image in visble wave length using 8 STI images. Red in this image is due to bad white balance that is enhanced in radar diagram representation

Using this method we have systematically compared temperature measured by the IR sensors and CIR-7 simulated visible image. In order to avoid the TSI shadower, sensors in North-west and North-east have been retained. Graph of the ratio "red / blue intensity" is plotted versus temperature on figure 8. A linear relation between this ratio and cloud temperature appears to be evident. Nevertheless a relative measurement spread is present (red and green curve).

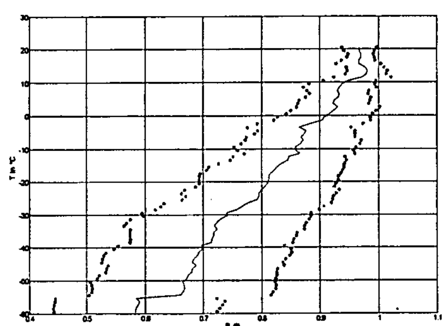

Figure 8 : Temperature versus ratio of intensity R/B obtained from 1400000 measures.

5. Dynamic

We are interested in retrieval cloud motion from one image to another. For the TSI a simple video with one image every 30s shows that it is enough to retrieve global motion of cloud using classical image processing algorithm. For CIR-7, sampling with a speed of one image every 200s is not enough with interlaced image. Nevertheless, a sampling speed of one image every 90s obtained recently with a newer CIR-13 instrument shows clearly that motion can be retrieved.

6. CONCLUSIONS

Despite of the slow speed sampling, the infrared cloud imaging CIR-7 system shows a good agreement with the TSI images. Great advantage of the infrared technique is that the system works day and night. In the visible domain cloud temperature can be retrieve using optical density with a significant relative error.

For cloud motion an image scan every 90s would allow the use of image processing algorithm to retrieve motion flow.

7. ACKNOWLEDGMENTS

Data were obtained from the Atmospheric Radiation. Measurement (ARM) Program sponsored by the U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research, Environmental Sciences Division.

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L7	3	((normal$4 same difference same snow same index) or (ndsi)) and ((Normal$4 same difference same vegetation same index) or (ndvi))	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/21 14:44

S1	50	("5739919" "5796716" "5828468" "5839089" "6011625" "6023470" "6178453" "6246468" "4149756" "4310011" "4484192" "4601303" "4965014" "5206806" "5294782" "5386106" "5406481" "5471541" "5489773" "5592402" "5602755" "5659493" "5699269" "5708503" "5848115" "5861891" "5920495" "5988862" "6034697" "6037896" "6051028" "6125327" "6137531" "6240511" "6330523" "6374198" "6388258" "6407735" "6420698" "6473079" "6512518" "6512993" "6608913" "6618689" "6619406" "6633290" "6701006" "6734849" "6738727" "6752008").pn.	US-PGPUB; USPAT	OR	ON	2005/06/21 14:38
S2	50	("5739919" "5796716" "5828468" "5839089" "6011625" "6023470" "6178453" "6246468" "4149756" "4310011" "4484192" "4601303" "4965014" "5206806" "5294782" "5386106" "5406481" "5471541" "5489773" "5592402" "5602755" "5659493" "5699269" "5708503" "5848115" "5861891" "5920495" "5988862" "6034697" "6037896" "6051028" "6125327" "6137531" "6240511" "6330523" "6374198" "6388258" "6407735" "6420698" "6473079" "6512518" "6512993" "6608913" "6618689" "6619406" "6633290" "6701006" "6734849" "6738727" "6752008").pn. and cloud	US-PGPUB; USPAT	OR	ON	2005/06/15 16:40
S3	40	("5739919" "5796716" "5828468" "5839089" "6011625" "6023470" "6178453" "6246468" "4149756" "4310011" "4484192" "4601303" "4965014" "5206806" "5294782" "5386106" "5406481" "5471541" "5489773" "5592402" "5602755" "5659493" "5699269" "5708503" "5848115" "5861891" "5920495" "5988862" "6034697" "6037896" "6051028" "6125327" "6137531" "6240511" "6330523" "6374198" "6388258" "6407735" "6420698" "6473079" "6512518" "6512993" "6608913" "6618689" "6619406" "6633290" "6701006" "6734849" "6738727" "6752008").pn. and point same cloud	US-PGPUB; USPAT	OR	ON	2005/06/15 16:41

S4	39	("5739919" "5796716" "5828468" "5839089" "6011625" "6023470" "6178453" "6246468" "4149756" "4310011" "4484192" "4601303" "4965014" "5206806" "5294782" "5386106" "5406481" "5471541" "5489773" "5592402" "5602755" "5659493" "5699269" "5708503" "5848115" "5861891" "5920495" "5988862" "6034697" "6037896" "6051028" "6125327" "6137531" "6240511" "6330523" "6374198" "6388258" "6407735" "6420698" "6473079" "6512518" "6512993" "6608913" "6618689" "6619406" "6633290" "6701006" "6734849" "6738727" "6752008").pn. and point same cloud and data same point	US-PGPUB; USPAT	OR	ON	2005/06/15 16:41
S5	4	("5739919" "5796716" "5828468" "5839089" "6011625" "6023470" "6178453" "6246468" "4149756" "4310011" "4484192" "4601303" "4965014" "5206806" "5294782" "5386106" "5406481" "5471541" "5489773" "5592402" "5602755" "5659493" "5699269" "5708503" "5848115" "5861891" "5920495" "5988862" "6034697" "6037896" "6051028" "6125327" "6137531" "6240511" "6330523" "6374198" "6388258" "6407735" "6420698" "6473079" "6512518" "6512993" "6608913" "6618689" "6619406" "6633290" "6701006" "6734849" "6738727" "6752008").pn. and point same cloud and data same point and infrared	US-PGPUB; USPAT	OR	ON	2005/06/15 16:45
S6	11	cirrus and point same cloud and data same point and infrared	US-PGPUB; USPAT	OR	ON	2005/06/15 16:49
S7	3	vnir-swir and cirrus and point same cloud and data same point and infrared	US-PGPUB; USPAT	OR	ON	2005/06/15 17:49
S8	3	vnir-swir and cirrus and point and cloud and data same point and infrared	US-PGPUB; USPAT	OR	ON	2005/06/15 17:00
S9	3	vnir-swir and cirrus and point and cloud and data and point and infrared	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/16 13:41

S10	3	vnir-swir and cirrus and infrared	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/15 17:50
S11	1	cloud and spectral same image$4 and aviris and modis and cirrus and infrared	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/15 17:38
S12	3	vnir adj swir and cirrus and infrared	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/15 17:39
S13	0	aviris and vnir adj swir and cirrus and infrared	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/15 17:39
S14	1	aviris and cirrus and infrared	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/15 17:40
S15	1	aviris and cirrus and infrared and point	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/15 17:49
S16	1	aviris and cirrus and infrared and point and cloud	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/15 17:41
S17	1	aviris and cirrus and infrared and point and cloud and visible	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/15 17:44

S18	1	aviris and cirrus and infrared and point and cloud and visible and infrared	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/15 17:48
S20	1	aviris and cirrus and infrared and point and cloud and visible and infrared and data	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/15 17:48
S22	1	aviris and cirrus and infrared and point and cloud and visible and infrared and data and comparison	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/15 17:46
S23	5	("5884226").URPN.	USPAT	OR	ON	2005/06/15 17:47
S24	3	(boright same arthur).in.	US-PGPUB; USPAT	OR	ON	2005/06/15 17:50
S25	3	vnir-swir and cloud and shadow and detection	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/15 17:51
S26	4	vnir-swir and cloud	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/16 12:47
S27	1	"l1" same norm$5 and "l2" same norm$5 and prestack and seismic and data	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/16 12:52
S28	1	"l1" same norm$7 and "l2" same norm$7 and prestack and seismic and data	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/16 12:52
S29	0	norm$7 same (avo or rms) and hyperbolic same window and prestack and seismic and data and (huber or ekblom) same model	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/16 12:54

S30	0	norm$7 and (avo or rms) and hyperbolic same window and prestack and seismic and data and (huber or ekblom) same model	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/16 12:54
S31	0	norm$7 and (avo or rms) and hyperbolic and window and prestack and seismic and data and (huber or ekblom) same model	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/16 12:54
S32	2	norm$7 and (avo or rms) and hyperbolic and window and prestack and seismic and data and (huber or ekblom) and model	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/16 13:04
S33	2	norm$7 and (avo or rms) and hyperbolic and window and prestack and seismic and data and (huber or ekblom) and model$3	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/16 13:04
S34	1	("5563949").PN.	US-PGPUB; USPAT; USOCR	OR	ON	2005/06/16 13:04
S35	5	("3638178" | "3931609" | "4403312" | "4799201" | "4892807").PN.	US-PGPUB; USPAT; USOCR	OR	ON	2005/06/16 13:05
S36	3	vnir-swir and cirrus and point and cloud and data and point and infrared	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/16 13:41
S37	4	cloud$3 same shadow$3 same detection$3 and data$3 same point$3 same image$4 and infrared$3	US-PGPUB; USPAT	OR	ON	2005/06/20 17:36
S38	4	cloud$3 same shadow$3 same detection$3 and data$3 same point$3 same image$4 and infrared$3	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/20 17:37
S39	3	cirrus same band same comparator and cloud same mask and imag$3	US-PGPUB; USPAT	OR	ON	2005/06/21 12:45
S40	3	cirrus and band and comparator and cloud same mask and imag$3	US-PGPUB; USPAT	OR	ON	2005/06/21 12:45

S41	3	cirrus and band and comparator and cloud and mask and imag$3	US-PGPUB; USPAT	OR	ON	2005/06/21 12:45
S42	3	cirrus and comparator and cloud and mask and imag$3	US-PGPUB; USPAT	OR	ON	2005/06/21 12:45
S43	106	comparator and cloud and mask and imag$3	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/21 12:46
S44	3	comparator and cloud and mask and imag$3 and cloud same cirrus	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/21 12:46
S45	3	comparator and cloud and mask and imag$3 and cirrus	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/21 12:46
S46	106	comparator and cloud and mask and imag$3 and cloud	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/21 12:47
S47	55	comparator and cloud and mask and imag$3 and cloud and data same point	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/21 12:52
S48	11	comparator and cloud and mask and imag$3 and cloud and data same point and (infrared or (short same wavelength))	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/21 12:49
S49	7	comparator and cloud and mask and imag$3 and cloud and data same point and (infrared or (short same wavelength)) and spectral	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/21 12:50
S50	0	comparator and cloud and mask and imag$3 and cloud and data same point and (infrared or (short same wavelength)) and spectral and vegtation	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/21 12:49

S51	3	comparator and cloud and mask and imag$3 and cloud and data same point and (infrared or (short same wavelength)) and spectral and indice$3	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/21 12:50
S52	3	comparator and cloud and mask and imag$3 and cloud and data same point and (infrared or (short same wavelength)) and indice$3	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/21 13:00
S53	8	cloud and mask and imag$5 and cloud same point and (infrared or (short same wavelength)) and indice$3	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/21 13:01
S54	3	cloud and mask and imag$5 and cloud same point and (infrared or (short same wavelength)) and indice$3 and cirrus	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2005/06/21 13:01

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2	X	X	US 20050114026 A1	20050526	25
3	X	X	US 20050111692 A1	20050526	18

	Title	Current OR	Current XRef
1	Cloud shadow detection: VNIR-SWIR	702/3	
2	Sub-visible cloud cover assessment: VNIR-SWIR	702/3	
3	Cloud cover assessment: VNIR-SWIR	382/100	